Environmental And Public Health Implications of Open Municipal Solid Waste Burning in Ilorin Metropolis, Nigeria

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***Abstract*—Open burning of municipal solid waste (MSW) remains one of the major contributors to atmospheric pollution and environmental health challenges in developing countries. This study assessed the environmental and public health implications of open municipal solid waste burning in Ilorin Metropolis, Nigeria. Five major dumpsites located within residential areas namely Amilegbe, Zango, Gaa Imam, Asa Dam Road, and Lao Hajj Camp were selected for investigation. Waste characterization was conducted to determine the composition of municipal wastes, while particulate matter concentrations including PM1.0, PM2.5, PM4.0, PM10, and Total Suspended Particulates (TSP) were measured using an Aerocet 831 handheld particle monitor. Emission estimates of gaseous pollutants such as sulfur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), methane, and non-methane total organic compounds (TOC) were evaluated using emission factor approaches. Results revealed significant variations in waste composition across the dumpsites, with plastics, paper, leather, and clothing materials dominating the waste streams. Measured 24-hour average PM10 concentrations ranged from 34.7 to 219.7 µg/m³, while PM2.5 concentrations ranged from 4.6 to 27.2 µg/m³. Dumpsites located at Zango, Asa Dam Road, and Lao Hajj Camp exceeded the World Health Organization (WHO) and National Ambient Air Quality Standards (NAAQS) permissible limits for particulate matter. Zango dumpsite recorded the highest pollutant emission estimates with particulate emissions of 904.03 kg/yr and carbon monoxide emissions of 4746.17 kg/yr. Elevated particulate concentrations and gaseous emissions from open waste burning pose substantial risks to public health, including respiratory disorders, cardiovascular diseases, and environmental degradation.**
The study concludes that uncontrolled open burning of municipal solid waste significantly deteriorates ambient air quality within Ilorin metropolis and exposes nearby residents to

severe environmental and health hazards. The implementation of sustainable waste management strategies, stricter environmental regulations, and public awareness campaigns is therefore recommended to mitigate pollutant emissions and improve urban environmental quality.

***Index Terms*—Municipal solid waste; Open burning; Particulate matter; Air pollution; Public health; Emission inventory; Ilorin metropolis; Nigeria**

I. INTRODUCTION

Environmental pollution remains one of the most serious global challenges threatening ecological sustainability and public health, particularly in rapidly urbanizing developing countries. Pollution arises from the release of harmful substances into the environment through domestic, industrial, agricultural, and commercial activities, resulting in adverse effects on ecosystems and human well-being. Among the various forms of environmental pollution, air pollution has gained increasing global attention because of its strong association with respiratory diseases, cardiovascular complications, climate change, and premature mortality (WHO, 2021).

Rapid urbanization, industrialization, and population growth have substantially increased municipal solid waste generation worldwide. According to Guerrero et al. (2013), the inability of many developing nations to establish efficient waste management systems has intensified environmental degradation and urban sanitation challenges. Municipal solid waste (MSW) generally consists of paper, plastics, organic materials, metals, textiles, leather, rubber, glass, and electronic wastes generated from residential, commercial, institutional, and industrial activities (Babayemi and Dauda, 2009). In many low- and middle-income countries, poor waste collection systems, inadequate landfill facilities, weak environmental regulations, and insufficient financial resources have made open dumping and open burning the dominant methods of waste disposal (Ahmed, 2013).

Open burning of municipal solid waste is recognized globally as a major source of atmospheric pollution. The process involves uncontrolled combustion of mixed waste materials in open dumpsites, roadsides, and residential environments. During combustion, substantial quantities of toxic pollutants are released into the atmosphere, including particulate matter (PM), carbon monoxide (CO), sulfur oxides (SOx), nitrogen oxides (NOx), methane, volatile organic compounds (VOCs), dioxins, furans, and polycyclic aromatic hydrocarbons (PAHs) (Zhang et al., 2011). Das et al. (2018) estimated that open waste burning contributes significantly to urban air pollution and greenhouse gas emissions in many developing countries. Similarly, Gangwar et al. (2019) reported elevated concentrations of particulate pollutants around illegal waste burning sites, posing severe health risks to exposed populations.

Globally, it has been estimated that approximately 620–970 million tons of waste are openly burned annually, particularly in developing countries where waste management infrastructure remains inefficient (Wiedinmyer et al., 2014). Open burning contributes substantially to global

particulate emissions and environmental degradation. According to Gulia et al. (2018), poor urban air quality resulting from anthropogenic emissions remains one of the major environmental challenges facing rapidly growing cities worldwide.

Particulate matter emitted during waste combustion is among the most dangerous pollutants due to its ability to penetrate deeply into the respiratory tract and bloodstream. Airborne particles are generally classified according to aerodynamic diameter into PM1.0, PM2.5, PM4.0, PM10, and total suspended particulates (TSP). Fine particles such as PM2.5 and PM10 are particularly harmful because of their prolonged atmospheric residence time and inhalation potential (Hautala, 2000). The World Health Organization (WHO, 2021) identified particulate pollution as one of the leading environmental causes of premature mortality globally. Long-term exposure to elevated concentrations of particulate matter has been associated with asthma, bronchitis, chronic obstructive pulmonary disease, cardiovascular disorders, lung cancer, and neurological complications (Raaschou-Nielsen et al., 2013).

In addition to particulate pollution, open burning of municipal wastes releases several gaseous pollutants with severe environmental and health implications. Lan et al. (2016) reported that sulfur dioxide exposure contributes significantly to respiratory irritation and pulmonary complications, while carbon monoxide exposure has been associated with headaches, dizziness, cardiovascular dysfunction, and reduced oxygen transport in humans. Toxic organic compounds such as dioxins, furans, and polycyclic aromatic hydrocarbons generated during incomplete combustion also possess carcinogenic and mutagenic properties capable of causing long-term health complications (Triassi et al., 2015).

Nigeria, the most populous country in Africa, faces enormous challenges in municipal solid waste management due to rapid urbanization, population growth, and inadequate environmental infrastructure. According to Ahmed (2013), millions of tons of municipal waste are generated annually in Nigeria, yet only a small proportion is properly collected and managed. Delayed waste collection, indiscriminate dumping, and uncontrolled burning of wastes are common in many Nigerian cities, thereby contributing significantly to environmental pollution and public health concerns.

Ilorin metropolis, the capital city of Kwara State, has experienced rapid urban expansion and population growth over the years. The city comprises Ilorin East, Ilorin West, and Ilorin South Local Government Areas with increasing residential, commercial, and industrial activities (NPC, 2006). As population density increases, the quantity of municipal solid waste generated within the metropolis also rises considerably. However, existing waste management systems have proven inadequate in addressing the growing waste burden. Abdus-Salam (2009) observed that indiscriminate waste disposal practices constitute major environmental problems within Ilorin metropolis. Similarly, Olagunju and Adeniyi (2018) noted that poor waste management infrastructure and irregular waste evacuation have contributed to the emergence of illegal dumpsites across the city.

The continuous burning of wastes at dumpsites located within residential neighborhoods exposes nearby residents to elevated concentrations of particulate matter and toxic gaseous pollutants.

Akpeimeh et al. (2019) reported that populations residing close to open dumpsites are highly vulnerable to respiratory infections and other pollution-related illnesses due to prolonged exposure to airborne contaminants. Studies conducted in several developing countries have similarly linked open waste burning activities to increased environmental pollution and adverse public health outcomes (Mazza et al., 2015; Das et al., 2018).

Despite increasing concerns regarding the environmental and health consequences of waste burning, limited studies have comprehensively investigated particulate emissions and pollutant inventories associated with open municipal waste burning within Ilorin metropolis. Most existing studies have focused primarily on waste management practices without adequately quantifying particulate concentrations and associated health implications around dumpsites. There is therefore a critical need to evaluate the contributions of open municipal solid waste burning to ambient air pollution and public health exposure within the study area.

This study therefore assesses the environmental and public health implications of open municipal solid waste burning in Ilorin metropolis, Nigeria. Specifically, the study aims to characterize waste composition at selected dumpsites, determine particulate matter concentrations, estimate pollutant emissions associated with waste burning activities, and evaluate potential public health risks posed by atmospheric pollutants. Findings from this study are expected to provide valuable scientific information for policymakers, environmental protection agencies, waste management authorities, and public health institutions toward the development of sustainable waste management strategies and effective air pollution control measures in urban Nigeria.

II. METHODOLOGY AND MATERIALS

A. Description of Study Area

This study was conducted in Ilorin metropolis, the capital city of Kwara State, North-Central Nigeria. Ilorin occupies an estimated land area of approximately 765 km² and has a population of about 814,192, making it one of the largest urban centers in North-Central Nigeria (NPC, 2016). The metropolis comprises three major Local Government Areas (LGAs), namely Ilorin East, Ilorin West, and Ilorin South.

Geographically, Ilorin lies within the transitional zone between the southern forest and northern savannah regions of Nigeria. The climate of the city is characterized by distinct wet and dry seasons. The rainy season generally commences in late April and extends to October, while the dry season spans from November to April. Ambient temperature within the metropolis ranges from 33°C to 35°C during the harmattan period (November–January) and increases to approximately 34°C–37°C between February and April (WWO, 2019). Annual rainfall ranges from 990.3 mm to 1318 mm, while relative humidity varies between 75% and 88% during the wet season and decreases to approximately 35%–80% during the dry season.

Rapid urbanization, population growth, and increasing socioeconomic activities within Ilorin metropolis have resulted in substantial increases in municipal solid waste generation. However, inadequate waste management infrastructure and poor waste disposal practices have contributed

to the emergence of illegal dumpsites and frequent open burning of wastes across residential areas. These practices have become major sources of atmospheric pollution and environmental degradation within the city.

B. Selection of Sampling Location

Five major illegal municipal solid waste dumpsites were purposively selected across Ilorin metropolis based onwaste generation intensity, accessibility, population density, and prevalence of open waste burning activities. The selected sampling locations include:

1. Amilegbe (SP1)
2. Zango (SP2)
3. Gaa Imam (SP3)
4. Asa Dam Road (SP4)
5. Lao Hajj Camp (SP5)

These locations represent highly populated urban neighborhoods where open burning of municipal solid waste frequently occurs. Waste samples from each dumpsite were collected and characterized to determine waste composition and estimate pollutant emissions associated with combustion activities.

The geographical coordinates of each sampling location were determined using a handheld Global Positioning System (GPS) device. Table 1 presents the coordinates of the selected sampling points.

Table 1: Sample points and coordinates of location

Serial Number	Sample Code	Sample Location	Latitude	Longitude
1	SP 1	Amilegbe	N $8^0$29’44.924’’	E $4^0$33’54.056’’
2	SP 2	Zango	N $8^0$31’18.173’’	E $4^0$35’21.617’’
3	SP 3	Gaa Imam	N $8^0$27’44.866’’	E $4^0$34’4.3395’’
4	SP 4	Asa Dam Rd	N 8°27'9.91"	E 4°33'15.96"
5	SP 5	Lao Hajj Camp	N $8^0$27’8.8005’’	E $4^0$30’41.881’’

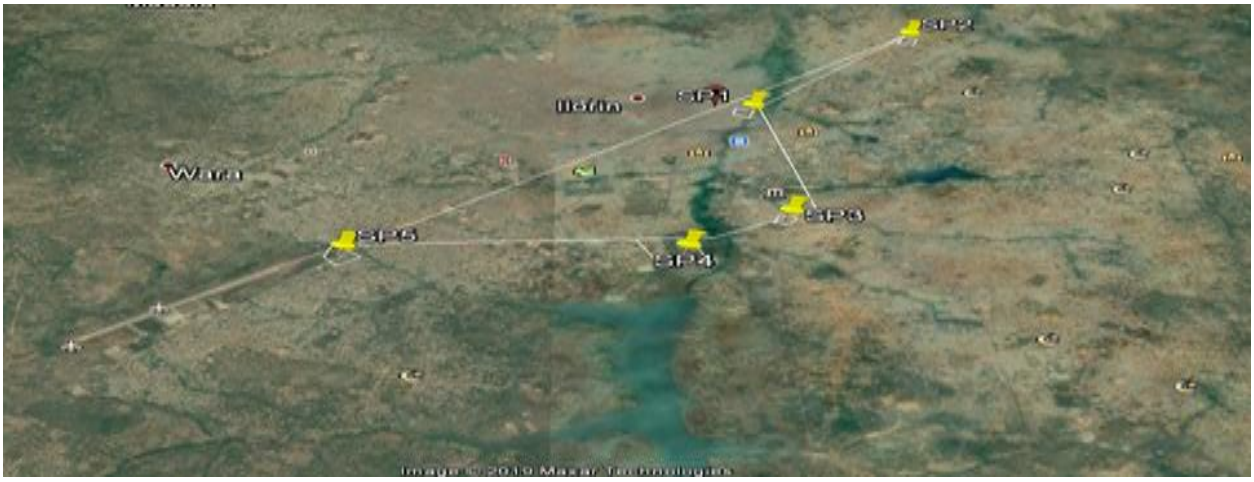


Fig 1: Map showing all selected sampling locations

Plate 1: Sample Point 1 (SP1); Amilegbe, Sample Point 2 (SP2); Zango, Sample Point 3(SP3); Gaa Imam, Sample Point 4 (SP4); Asa Dam Road respectively & Sample Point 5 (SP5); Lao Hajj Camp.

C. Waste Characterization

Municipal solid waste characterization was conducted at each selected dumpsite to determine the composition and distribution of waste materials. Waste samples were manually collected from representative portions of each dumpsite and sorted into different categories including plastics, paper, bottles, leather, clothing materials, rubber, foam, organic waste, wood, and metals.

Each waste component was separately weighed using standard weighing procedures to determine its percentage composition within the dumpsite. The characterization process enabled the identification of dominant combustible materials contributing to atmospheric emissions during open burning activities.

The composition analysis also provided information necessary for estimating pollutant emissions associated with the combustion of municipal solid waste at each sampling location.

D. Particulate Matter Sampling and Measurement

Ambient particulate matter concentrations were measured at each selected dumpsite during active waste burning periods using an AEROCET 831 handheld particulate mass monitor. The instrument is a lightweight, battery-operated particle counter capable of simultaneously measuring particulate fractions including PM1.0, PM2.5, PM4.0, PM10, and Total Suspended Particulates (TSP).

The AEROCET 831 instrument stores up to 2500 sampling events and provides real-time particulate concentration measurements. The monitor operates continuously for approximately 8 hours using an internal rechargeable battery and allows data transfer through a USB interface.

During field measurements, the particulate monitor was positioned at approximately 1.5 m above ground level to minimize interference from fugitive dust particles generated by human activities and surface disturbances. Sampling was conducted at different points within each dumpsite to ensure representative measurements of ambient particulate concentrations.

Measurements were recorded at one-minute intervals during the monitoring period. The obtained particulate concentrations were extrapolated to 8-hour and 24-hour average concentrations for comparison with World Health Organization (WHO) and National Ambient Air Quality Standards (NAAQS).

E. Measurement of Dumpsite Dimensions

Physical dimensions of each dumpsite were measured using a standard measuring tape. The length, breadth, and estimated height of each dumpsite were determined during field surveys to estimate waste volume accumulation.

The measuring tape was stretched across the entire length and width of each dumpsite to obtain dimensional measurements in meters. The estimated dimensions were subsequently used to calculate the approximate volume of accumulated waste materials at each location.

Waste volume estimation was performed using the frustum of pyramid formula with certain assumptions made regarding waste pile geometry. This estimation was necessary for evaluating the quantity of waste available for combustion and associated pollutant generation potential.

Fig 2: Aerocet 831 Handheld Particle Counter & Measuring Tape

F. Estimation of Waste Generation and Population Contribution

The number of households utilizing each dumpsite was estimated through spatial mapping and field observations within surrounding neighborhoods. An average household size of six persons per household was assumed based on local demographic characteristics and previous population estimates within the study area.

The estimated number of households contributing wastes to each dumpsite was used to approximate waste generation intensity and potential pollutant emission rates associated with open burning activities.

G. Air Quality Standards and Exposure Assessment

Measured particulate matter concentrations were compared with established air quality guidelines provided by the World Health Organization (WHO, 2021) and the United States National Ambient Air Quality Standards (NAAQS). These standards were used as benchmark limits for evaluating ambient air quality conditions and potential public health implications within the study area.

Human exposure to elevated concentrations of particulate matter has been associated with respiratory diseases, cardiovascular disorders, neurological complications, and premature mortality. Exceeding the permissible concentration limits specified by regulatory agencies indicates deteriorating ambient air quality and increased environmental health risks.

Table 2 presents the WHO and NAAQS guideline limits for PM2.5 and PM10 concentrations used for comparison in this study.

Table 2: $PM_{2.5}$ and PM_{10} standards from various air quality regulatory bodies in ($\mu g/m^3$)

		WHO		NAAQS
PM_{10} Annual		20		-
1-Hour		-		200
24-Hour		50		150
$PM_{2.5}$ Annual		10		15.0
1-Hour		-		-
24-Hour		25		35
Sources:USEPA,2016;	WHO 2018.			

H. Data Analysis

Experimental data obtained from particulate monitoring and waste characterization were analyzed using Microsoft Excel software. Statistical analyses including mean, minimum, maximum, and standard deviation were computed for each particulate fraction across all sampling locations.

Measured particulate concentrations were extrapolated to 8-hour and 24-hour averages prior to comparison with established regulatory standards. Graphical representations were also developed to illustrate variations in particulate concentrations among the selected dumpsites.

Comparative analyses were conducted to identify sampling locations with the highest and lowest particulate concentrations as well as spatial variations in pollutant distribution across Ilorin metropolis.

The estimated dumpsite volumes and waste composition data were further used to evaluate pollutant emission potentials associated with open municipal solid waste burning activities within the study area.

III. RESULTS AND DISCUSSION

A. Waste Composition of Selected Dumpsite

The percentage composition of municipal solid wastes collected from the selected dumpsites is presented in Table 3. Considerable variations were observed in the composition of wastes among the sampling locations, indicating differences in socioeconomic activities, consumption patterns, and waste disposal behaviors within the study area.

Table 3: Percentage Composition of Waste Materials from Selected Dumpsites

Sample points	Bottles (%)	Plastics (%)	Paper (%)	Leather (%)	Can (%)	Slippers (%)	Clothes (%)	Organic Wastes (%)	Foam (%)	Rubber (%)	Wood (%)
1	16.79	11.84	7.57	57.15	6.64	-	-	-	-	-	-
2	9.31	13.99	7.30	3.15	-	9.53	43.04	13.68	-	-	-
3	5.08	46.41	5.89	8.55	-	-	34.11	-	-	-	-
4	13.44	17.24	68.24	-	-	-	-	-	1.08	24.11	2.02
5	-	21.84	24.20	-	-	22.63	-	-	5.19		

SP1 (Amilegbe) was predominantly characterized by leather materials, accounting for 57.15% of the total waste composition. The dominance of leather waste may be attributed to the presence of

commercial and artisanal activities involving leather processing and usage within the area. SP2 (Zango) contained a high proportion of clothing materials (43.04%), suggesting intensive residential and commercial activities associated with textile usage and disposal.

At SP3 (Gaa Imam), plastics constituted the highest percentage (46.41%), indicating widespread consumption and disposal of plastic products within the community. The dominance of plastic wastes is environmentally significant because plastics generate toxic emissions such as dioxins, furans, and volatile organic compounds during combustion (Zhang et al., 2011). SP4 (Asa Dam Road) and SP5 (Lao Hajj Camp) were dominated by paper materials, accounting for 68.24% and 24.20%, respectively. The high paper content observed at these locations may be associated with commercial activities, packaging materials, and domestic refuse generation.

The predominance of combustible materials such as plastics, paper, leather, textiles, rubber, and foam across the selected dumpsites indicates high pollutant generation potential during open burning activities. Similar observations were reported by Babayemi and Dauda (2009), who identified combustible municipal wastes as major contributors to atmospheric pollution in urban Nigerian cities.

B. Particulate Matter Concentrations

1. One-Hour Average Particulate Concentrations

Table 4 presents the measured one-hour average concentrations of PM1.0, PM2.5, PM4.0, PM10, and Total Suspended Particulates (TSP) across the selected dumpsites.

Table 4a: One-Hour Average Particulate Concentrations at Selected Dumpsites

Sample Locations	$PM_{1.0}$ ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	$PM_{4.0}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	TSP ($\mu g/m^3$)
SP1	13.1	11.2	27.8	84.4	115.5
SP2	37.9	51.1	84.4	269	402.1
SP3	24.6	45.2	65.0	103.8	125.9
SP4	24.9	27.3	125.9	534.75	628.3
SP5	42.4	67.1	114.5	392.8	358.8

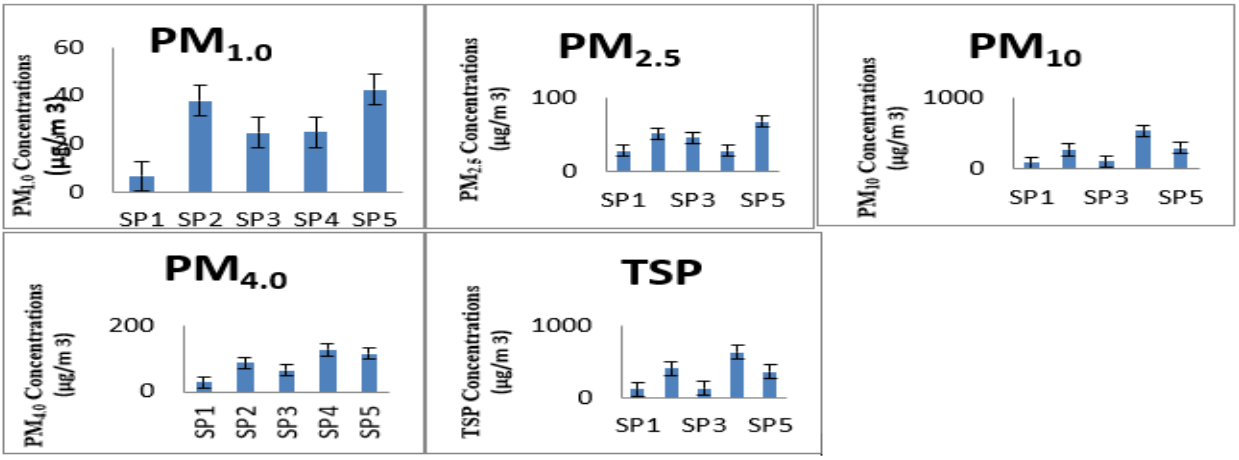


Fig 3a: 1-hour average particulate concentrations in each dumpsite.

The measured one-hour particulate concentrations varied considerably among the sampling locations. PM1.0 concentrations ranged from 13.1–42.4 µg/m³, PM2.5 ranged from 11.2–67.1 µg/m³, PM4.0 ranged from 27.8–125.9 µg/m³, PM10 ranged from 84.4–534.75 µg/m³, while TSP ranged from 115.5–628.3 µg/m³.

SP4 (Asa Dam Road) recorded the highest PM10 concentration of 534.75 µg/m³ and TSP concentration of 628.3 µg/m³, indicating severe atmospheric pollution within the area. SP5 (Lao Hajj Camp) also exhibited elevated PM2.5 and PM10 concentrations. The high particulate concentrations observed at these locations may be attributed to frequent waste burning activities, high waste accumulation, traffic emissions, and the proximity of the dumpsites to major transportation routes.

SP2 (Zango) similarly recorded elevated particulate concentrations across all particle sizes. The relatively high pollution levels observed at Zango may be linked to the large population utilizing the dumpsite and increased waste generation rates within the area. Similar findings were reported by Gangwar et al. (2019), who observed elevated particulate concentrations around illegal waste burning sites in densely populated urban environments.

2. Eight-Hour Extrapolated Particulate Concentrations

The extrapolated eight-hour average particulate concentrations are presented in Table 4b.

Table 4b: Eight-Hour Extrapolated Particulate Concentrations

Sample Locations	$PM_{1.0}$ (µg/m 3)	$PM_{2.5}$ (µg/m 3)	$PM_{4.0}$ (µg/m 3)	PM_{10} (µg/m 3)	TSP (µg/m 3)
SP1	3.7	6.3	15.5	47.2	64.5
SP2	21.2	28.5	48.3	150.3	224.6
SP3	13.7	24.8	36.3	58.0	70.9
SP4	13.9	15.2	70.4	298.7	351.0
SP5	23.7	187.3	64.0	163.6	200.5

The extrapolated eight-hour average concentrations revealed persistent elevated particulate levels across several sampling points. SP4 (Asa Dam Road) recorded the highest PM10 concentration of 298.7 µg/m³, while SP5 (Lao Hajj Camp) recorded the highest PM2.5 concentration of 187.3 µg/m³. These values indicate severe short-term air quality deterioration within the affected neighborhoods.

The high concentrations of fine particulate matter observed at SP5 are particularly concerning because PM2.5 particles can penetrate deeply into the lungs and bloodstream, thereby increasing the risks of respiratory and cardiovascular diseases (WHO, 2021).

3. Twenty-Four Hour Extrapolated Particle Concentrations

The extrapolated 24-hour average particulate concentrations are presented in Table 4c.

Table 4c: Twenty-Four Hour Extrapolated Particulate Concentrations

Sample Locations	$PM_{1.0}$ (µg/m 3)	$PM_{2.5}$ (µg/m 3)	$PM_{4.0}$ (µg/m 3)	PM_{10} (µg/m 3)	TSP (µg/m 3)

SP1	2.7	4.6	11.4	34.7	47.4
SP2	15.6	21.0	35.5	110.4	165.1
SP3	10.1	18.6	26.7	42.7	51.7
SP4	10.2	11.2	51.8	219.7	258.1
SP5	17.4	27.2	47.0	120.3	153.4

The extrapolated 24-hour particulate concentrations indicate significant spatial variations in ambient air quality across the selected dumpsites. PM10 concentrations ranged from 34.7–219.7 µg/m³, while PM2.5 concentrations ranged from 4.6–27.2 µg/m³.

SP2 (Zango), SP4 (Asa Dam Road), and SP5 (Lao Hajj Camp) recorded the highest PM10 concentrations within the study area. The elevated particulate concentrations observed at these locations may be attributed to increased waste combustion activities and traffic-related emissions from nearby highways.

Comparing the obtained results with the World Health Organization (WHO, 2021) guideline value of 50 µg/m³ for 24-hour PM10 concentrations revealed that SP2, SP4, and SP5 exceeded the recommended limit. Similarly, comparison with the National Ambient Air Quality Standards (NAAQS) 24-hour limit of 150 µg/m³ indicated that SP4 exceeded the permissible concentration threshold.

For PM2.5 concentrations, only SP5 exceeded the WHO 24-hour guideline value of 25 µg/m³, although all sampling locations remained below the NAAQS permissible limit of 35 µg/m³. The exceedance of WHO guideline values indicates deteriorating air quality conditions and increased health risks for populations residing around the dumpsites.

Long-term exposure to elevated concentrations of PM2.5 and PM10 has been associated with asthma, bronchitis, cardiovascular diseases, chronic obstructive pulmonary disease, lung cancer, and premature mortality (Raaschou-Nielsen et al., 2013).

C. Particulate Matter Distribution

The distribution of particulate matter fractions across the selected dumpsites showed that PM4.0 constituted the highest proportion of airborne particles, accounting for approximately 36% of total particulate concentrations. PM2.5 accounted for approximately 23%, while PM10, TSP, and PM1.0 accounted for 14%, 22%, and 7%, respectively which is shown in Figure 4 below.

The dominance of PM4.0 and PM2.5 particles indicates the prevalence of inhalable fine particles within the study area. These particles are capable of remaining suspended in the atmosphere for extended periods and can penetrate deeply into the human respiratory system.

The elevated concentrations of inhalable particles observed in this study suggest substantial public health concerns for residents exposed to continuous emissions from open waste burning activities.

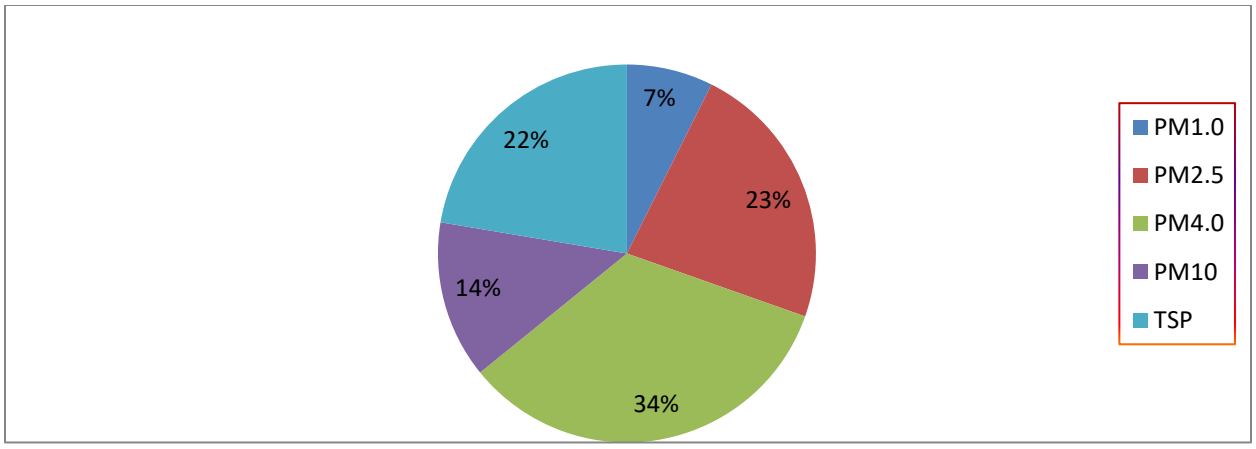


Fig 5: PM Percentage for each Dumpsite.

D. Pollutant Emission Estimates

Table 5a: Estimated Population and Household Distribution around Dumpsites

Sample Location	Number of Houses	Population Size
Amilegbe	87	522
Zango	120	720
Gaa Imam	67	402
Asa Dam Road	45	270
Lao Hajj Camp	53	318

A 15 km radius was mapped around each sampling location to estimate the population contributing wastes to the selected dumpsites. An average household size of six persons per household and a per capita waste generation rate of 0.43 kg/capita/day were adopted following Ayodele (2018).

Table 5b: Emission factors for Open Burning of municipal refuse

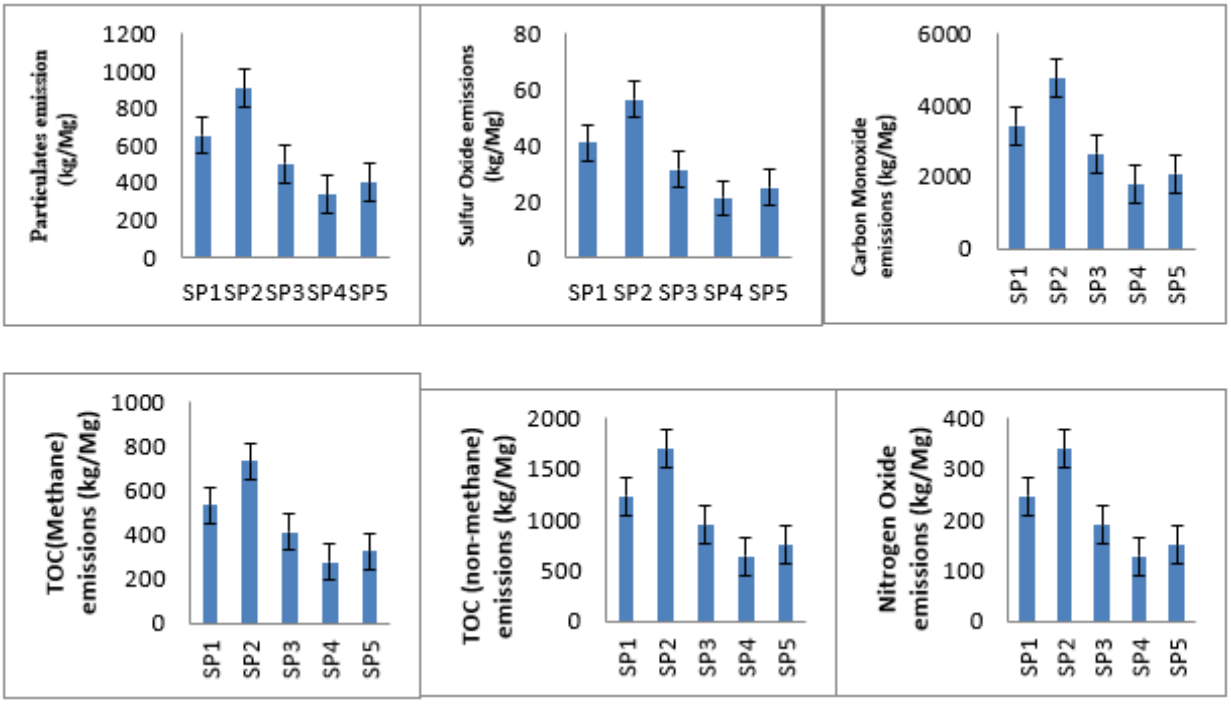
Source	Particulates	Sulfur Oxides	Carbon Monoxide	TOC		Nitrogen Oxides
				Methane	Non-methane	
Municipal Refuse kg/Mg	8	0.5	42	6.5	15	3

Source: EPA 2005

Table 5b shows the emission of particulates and other organic compounds. SP2 (Zango) was found to have the highest emission of pollutants when compared to other sample points, followed by SP1 (Amilegbe), then SP3 (Gaa Imam). However, comparing SP4(Asa Dam Road) and SP5(Lao Hajj Camp), SP5 was found to have higher emission of pollutants into the atmosphere than SP4(Asa Dam Road).

Table 5c: Emission values for each dumpsite.

Sample points	Particulates	Sulfur Oxides	Carbon Monoxide	TOC		Nitrogen Oxides
				Methane	Non-methane	
SP1	655.42	40.97	3441.06	532.55	1228.95	245.79
SP2	904.03	56.50	4746.17	734.53	1695.06	339.01
SP3	504.72	31.55	2649.78	410.09	946.35	189.27
SP4	339.04	21.19	1779.96	275.47	635.70	127.14
SP5	399.28	24.96	2096.22	324.42	748.65	149.73



(e) (f)

Fig 6(a-f): Gaseous pollutants emission during burning of wastes in each dumpsite.

Emission inventory analysis revealed substantial emissions of particulate matter and gaseous pollutants from open burning activities across the selected dumpsites. SP2 (Zango) recorded the highest emissions for all pollutants considered, including particulate emissions of 904.03 kg/yr and carbon monoxide emissions of 4746.17 kg/yr.

The elevated emissions observed at Zango are attributable to the larger population utilizing the dumpsite and the corresponding increase in waste generation rates. Increased waste accumulation results in more frequent combustion activities and consequently higher atmospheric emissions.

Carbon monoxide emissions were found to be particularly high across all sampling locations, indicating incomplete combustion of municipal wastes. Similarly, emissions of methane and non-methane total organic compounds contribute significantly to greenhouse gas accumulation and atmospheric pollution.

The release of sulfur oxides and nitrogen oxides during open burning activities also contributes to acid rain formation, respiratory irritation, and environmental degradation. Similar observations were reported by Das et al. (2018), who identified open municipal waste burning as a major contributor to urban atmospheric pollution in developing countries.

Overall, the findings of this study demonstrate that open municipal solid waste burning constitutes a significant source of environmental pollution and public health risks within Ilorin metropolis.

IV. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

This study evaluated the environmental and public health implications of open municipal solid waste burning at selected illegal dumpsites within Ilorin metropolis, Nigeria. Waste characterization analysis revealed considerable variation in waste composition among the selected dumpsites, with combustible materials such as plastics, paper, leather, clothing materials, rubber, and other biodegradable components constituting a significant proportion of the waste stream. The presence of these materials indicates a high potential for atmospheric pollutant generation during open burning processes.

Ambient particulate matter concentrations measured across the selected sampling locations using the AEROCET 831 particle monitor revealed elevated levels of PM1.0, PM2.5, PM4.0, PM10, and Total Suspended Particulates (TSP). Comparison of the measured concentrations with established air quality standards indicated that several sampling locations exceeded the guideline limits recommended by the World Health Organization (WHO) and National Ambient Air Quality Standards (NAAQS). Specifically, concentrations of PM2.5 and PM10 exceeded permissible limits at several locations, suggesting deteriorated air quality conditions around the dumpsites.

Among all the sampling locations, SP2 (Zango) recorded the highest particulate emission estimate of 904.03 kg/yr and had the largest estimated population contribution of 720 inhabitants. The elevated particulate concentration observed at this location may be attributed to increased population density, high waste generation rates, and continuous waste burning activities. Increased waste accumulation generally results in greater emission potential and atmospheric pollutant release during combustion.

Similarly, pollutant emission inventory analysis showed that SP2 (Zango) generated the highest estimated gaseous emissions among all selected sampling points, with carbon monoxide (CO), sulfur oxides (SO_2), methane and non-methane total organic compounds (TOC), and nitrogen oxides (NO_2) estimated at 4746.17 kg/yr, 56.50 kg/yr, 734.53 kg/yr and 1695.06 kg/yr, and 339.01 kg/yr respectively. The observed concentrations indicate substantial atmospheric pollutant loading resulting from open municipal waste burning activities.

The elevated concentrations of particulate matter and gaseous pollutants observed in this study represent significant environmental and public health concerns. Fine particulate matter (PM2.5) and coarse particles (PM10) are capable of penetrating deep into the human respiratory system and bloodstream, thereby increasing susceptibility to several health complications including

respiratory infections, asthma, chronic obstructive pulmonary disease, cardiovascular disorders, lung cancer, birth defects, and premature mortality.

Overall, the findings of this study demonstrate that open municipal solid waste burning significantly contributes to ambient air pollution and environmental degradation within Ilorin metropolis. The continued practice of uncontrolled waste combustion around residential environments poses substantial risks to ecosystem sustainability and public health. Consequently, effective intervention measures are required to reduce emissions associated with municipal waste burning and improve urban environmental quality.

B. Recommendations

Based on the findings obtained from this study, the following recommendations are proposed:

1. Government authorities should strengthen municipal solid waste management systems through improved waste collection, transportation, treatment, and disposal practices in order to reduce indiscriminate waste dumping and open burning activities.
2. Adequate financial and infrastructural support should be provided to environmental regulatory agencies, particularly the Kwara State Environmental Protection Agency (KWEPA), to improve operational efficiency and environmental monitoring activities.
3. Environmental policies and regulations relating to municipal waste management should be strengthened and strictly enforced. Appropriate sanctions and penalties should be imposed on individuals or organizations involved in illegal waste disposal and open burning practices.
4. Sustainable waste management approaches such as waste segregation, recycling, composting, resource recovery, and sanitary landfill practices should be encouraged as alternatives to open waste burning.
5. Continuous air quality monitoring programs should be established around major dumpsites and densely populated urban areas to facilitate early detection and management of pollutant exposure risks.
6. Public awareness and environmental education programs should be intensified to improve public understanding of the health and environmental consequences associated with open municipal waste burning.
7. Future studies should investigate the long-term health effects of exposure to particulate matter and gaseous emissions generated from municipal waste combustion within urban communities.

The implementation of these recommendations will contribute significantly toward reducing atmospheric pollution, improving environmental quality, and protecting public health within Ilorin metropolis and similar urban centers in developing countries.

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